



Pentaquark Search at Fermilab

Dmitry Litvintsev

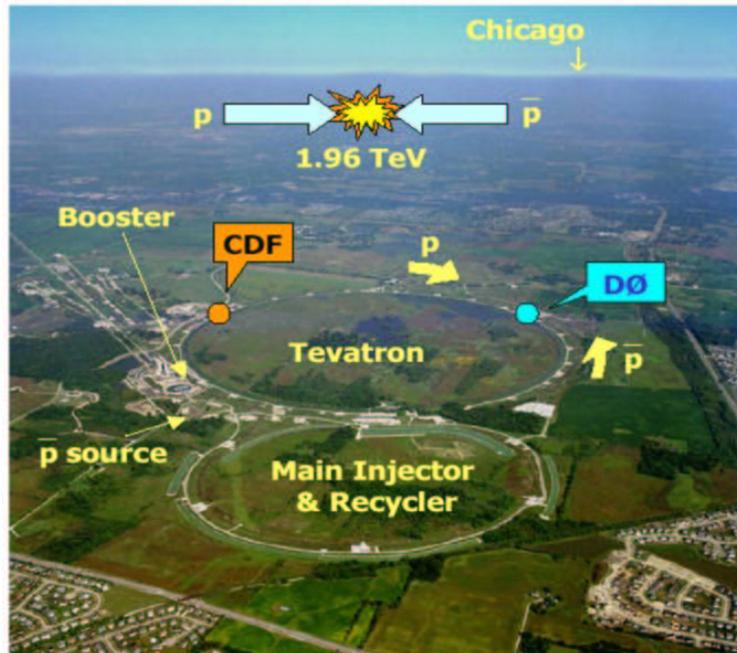
(Fermilab)

June 29, 2004

6th International Conference on
HYPERONS, CHARM & BEAUTY HADRONS

Tevatron at Fermilab

World's largest collider



- Tevatron performs very well after initially slow start
- $\int \mathcal{L} dt \sim 300 \text{pb}^{-1}$ ($\sim 250 \text{pb}^{-1}$ on tape)
- CDF & D0 efficiency $\sim 80\%$
- expect 2fb^{-1} for Run IIa
- $4 - 8 \text{fb}^{-1}$ by 2009

- 1 km ring radius; $p\bar{p}$ collisions, started 1984 $\sqrt{s} = 1.6 \text{TeV}$
- Run I (1992-1995) $\sqrt{s} = 1.8 \text{TeV}$, 6x6 bunches, $\mathcal{L}_{\text{inst}} = 1.6 \times 10^{31} \text{cm}^{-2}\text{s}^{-1}$, $\int \mathcal{L} dt = 110 \text{pb}^{-1}$
- 1996-2000 major upgrade for Run II
 - main injector
 - \bar{p} recycler
 - new synchrotron
 - upgraded \bar{p} source
- Run II started 2001:
 - $\sqrt{s} \sim 1.96 \text{TeV}$.
 - 36x36 colliding $p\bar{p}$ bunches
 - $10^{11}(10^{10})p(\bar{p})$ per bunch
 - $\mathcal{L}_{\text{inst}} = 7.2 \times 10^{31} \text{cm}^{-2}\text{s}^{-1}$ (record) (goal $8.1 \times 10^{31} \text{cm}^{-2}\text{s}^{-1}$)
 - high beam-beam crossing (inter-bunch spacing 396 ns), low pileup

Run II CDF Detector

Upgraded CDF Detector

tracking

- L00 + 5 layers of SVX + 2/1 outer layers of ISL ($1.5 < R < 30\text{cm}$, $|Z| < 45\text{cm}$). $r\phi$, rz , stereo strips. 720,000 channels. Si tracking up to $|\eta| < 2$.
- Central Outer Tracker (COT), 30,240 sense wires, 96 layer drift wire chamber. $\sigma(1/p_T) \sim 0.1\% / (\text{GeV}/c)$, $\sigma(\text{hit}) \sim 150\mu\text{m}$. dE/dx PID.

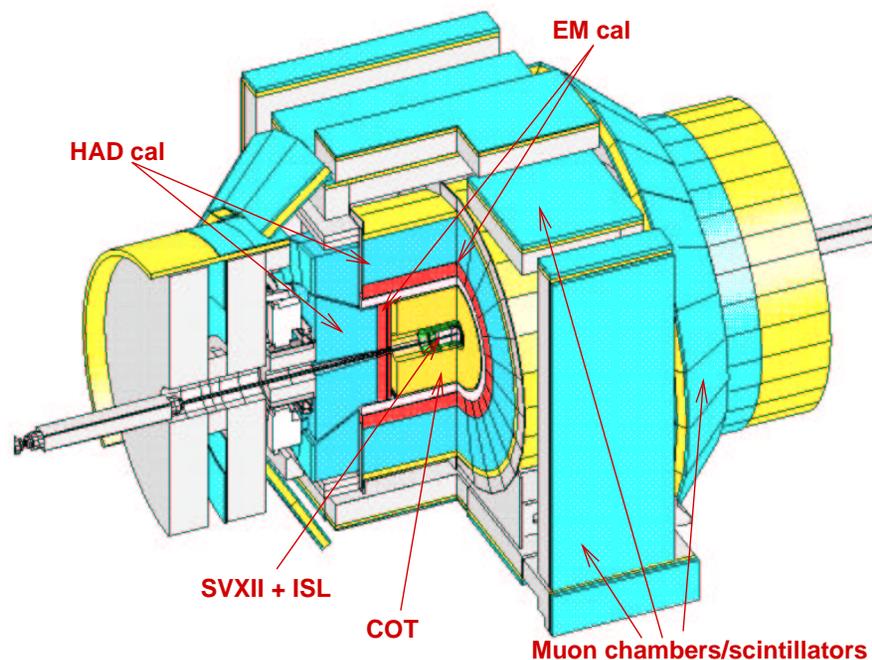
new plug calorimeter

extended muon coverage, $|\eta| < 1.5$

ToF system, (100 ps @ 150 cm)

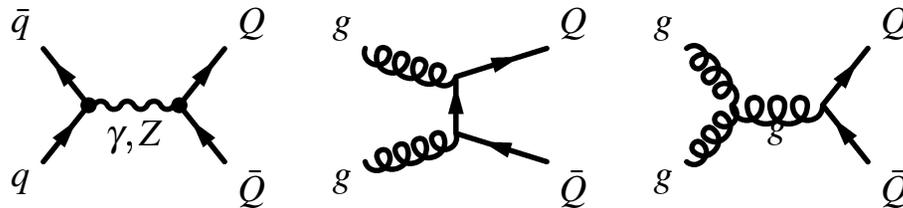
improved DAQ and trigger systems

- new frontend electronics
- Level 1 all digital, 132 ns pipeline
- 4000/300/70 Hz
- COT Tracks @ Level 1
- Si Tracks @ Level 2
- Full analysis @ Level 3
- First hadronic B-trigger
 - Silicon vertex trigger (SVT)
 - PID with ToF and dE/dx
 - Excellent mass resolution

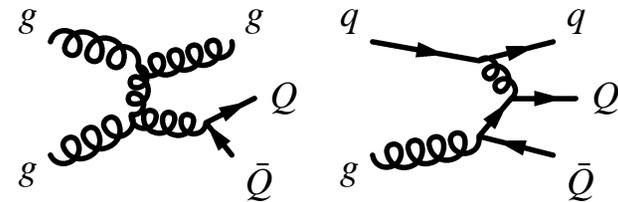


Heavy Flavor Production at Tevatron

LO Heavy quark production



NLO Heavy quark production



Accelerator	PEP-II, KEK	Tevatron
$\sigma(b\bar{b})$	1 nb	100 μb
$\sigma(b\bar{b}) : \sigma(\text{had})$	0.26	0.001
Production	$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$ coherent production	$p\bar{p} \rightarrow b\bar{b}X$ incoherent production
Environment	clean	messy
Hadrons produced	B^0, B^+	all
Boost	0.5	2-4
Kinematics	forward boost	$b\bar{b}$ not back-to-back, second b usually lost
pile-up	no	yes
Trigger	inclusive	selective
Beam energy constraint	yes	no

Q fragments into final states $B_u, B_d, B_s, \text{Baryon}_b$ with the following fractions:

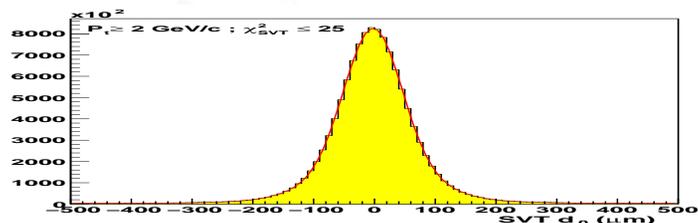
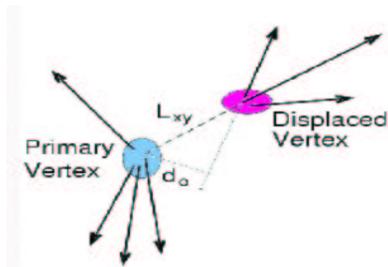
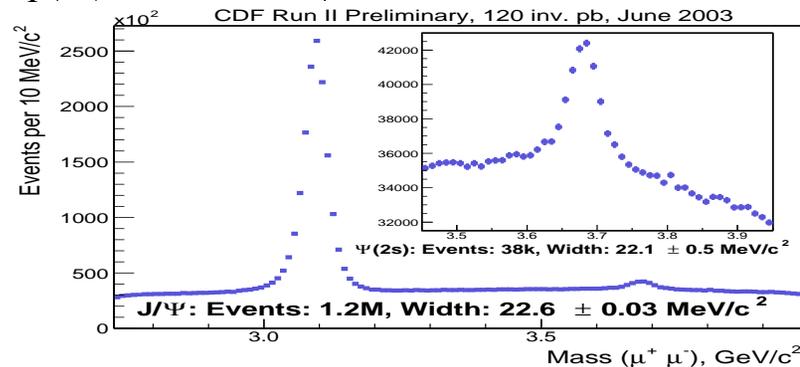
$$B_u : B_d : B_s : \text{Baryon}_b = 0.388 : 0.388 : 0.106 : 0.118$$

production of B_c is suppressed by 2-3 orders of magnitude as hard gluon process is needed

Heavy Flavor Triggers

- **unique displaced track trigger at CDF**
 - **Level 1**
 - ✓ XFT tracking in COT ($r - \phi$)
 - ✓ opposite charged track pair with $p_T > 2 \text{ GeV}/c$ each
 - ✓ $\Sigma p_T > 5.5 \text{ GeV}/c$
 - ✓ $\Delta\phi < 135^\circ$
 - **Level 2**
 - ✓ XFT track seeds SVT boards, that perform fast ($r - \phi$) track fit
 - ✓ require tracks impact parameter to be $0.012 < |d_0| < 0.1 \text{ cm}$

- **traditional di-muon triggers:**
 - two central muons ($|\eta| < 1$)
 - $p_T(\mu) > 1.5 \text{ GeV}/c$



$$\sigma(d_0)_{SVT} = 47 \mu m$$

Motivation

Recent flurry of reports of experimental evidences for a narrow exotic baryon state decaying to nK^+ , pK_S^0 at the mass of $\sim 1540 \text{ MeV}/c^2$, interpreted as 5-quark, ($uudd\bar{s}$), Θ^+ state predicted in chiral soliton model of baryons by Diakonov, Petrov, Polyakov (cf. hep-ph/9703373) revitalized interest in baryon spectroscopy.

✗ Not seen by Hera-B, Phenix, BES

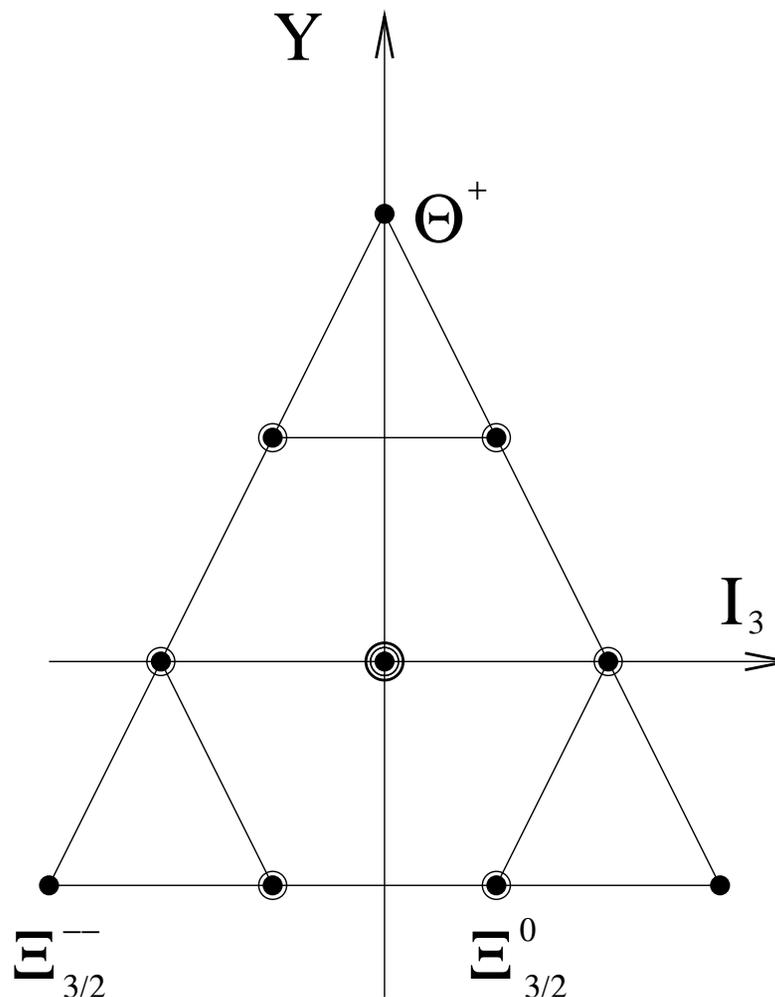
Followed by observation of Ξ^{--}, Ξ^0 , $M \sim 1860 \text{ MeV}/c^2$, decaying to $\Xi^-\pi^-, \Xi^-\pi^+$, by NA49 Experiment. Members of $S = -2$ ($qqss\bar{q}, q = u, d$) quadruplet of the SU(3) $\bar{10}$ of pentaquarks. (cf. Phys.Rev.Lett.92:042003,2004)

✗ Not seen by Hera-B, WA86

Recently H1 Experiment reported anti-charmed analogue ($uudd\bar{c}$) of the Θ^+ state decaying to $D^{*+}\bar{p}$. $M(\Theta_c^0) = (3,099 \pm 3 \pm 5) \text{ MeV}/c^2$ (cf. hep-ex/0403017)

All reported resonances are narrow with widths compatible with the apparatus resolutions.

All results are of relatively low statistics with between 20 and 100 events in peaks, signal to background ratios ranging from 1:1 to 1:3, statistical significance 3-5 σ . Verification on high statistics samples is warranted => PQ task force at CDF.

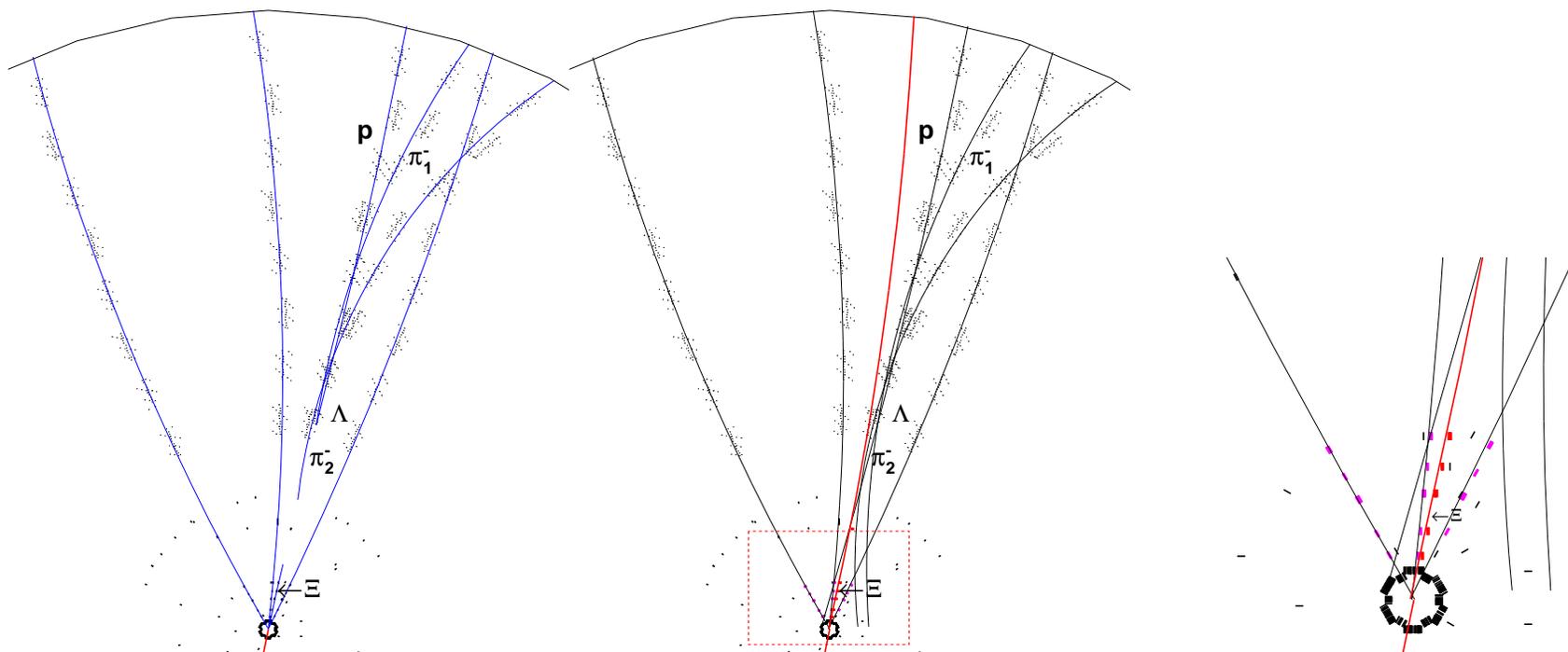




Cascade tracking in SVX at CDF

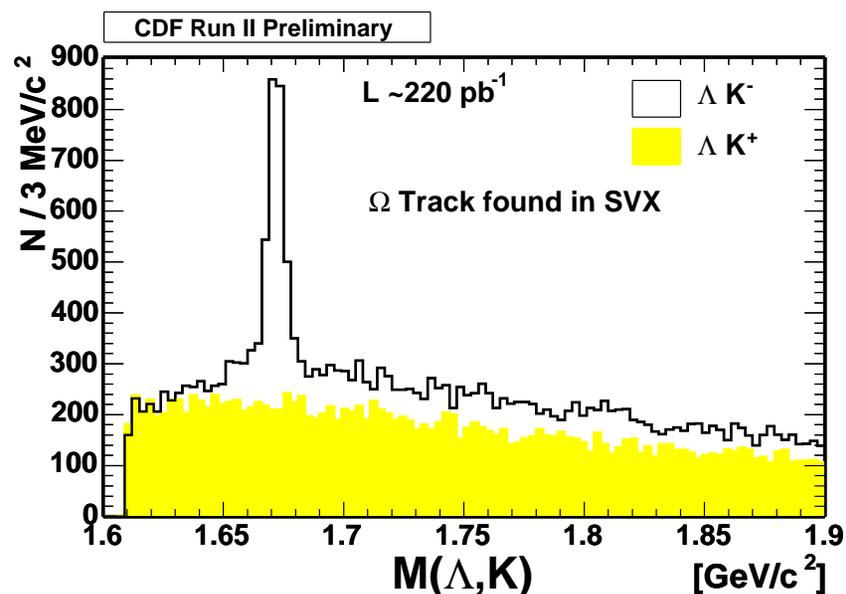
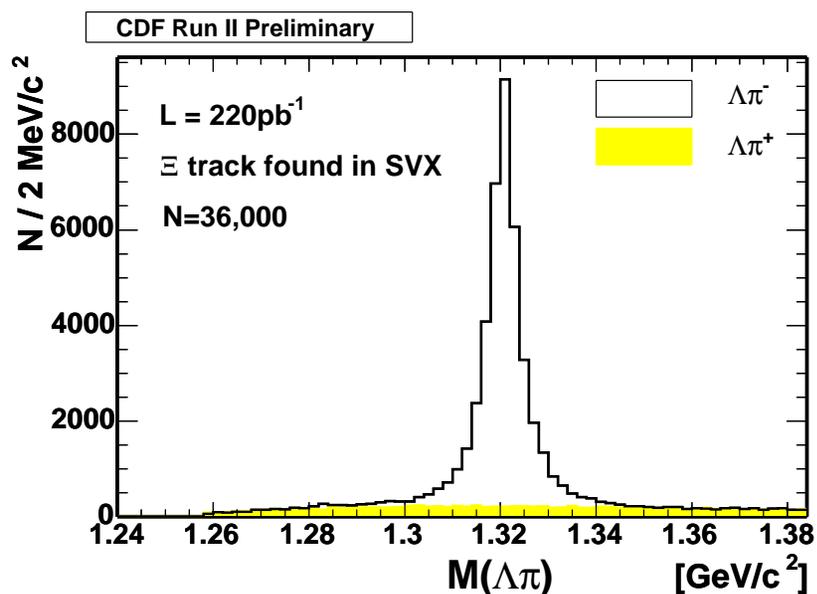
Hyperon Are Tracked in Silicon

→ $\Xi^- \rightarrow \Lambda^0 \pi^-$ is a long lived particle $c\tau = 4.91cm$. It leaves hits in SVX detector. CDF developed dedicated tracking Ξ in Silicon.



Tracked Hyperon signals

- CDF has developed tracking of long lived hyperons (Ξ and Ω) in the SVX detector.
- silicon tracking of hyperons improves momentum and impact parameter resolution as well as results in excellent background suppression



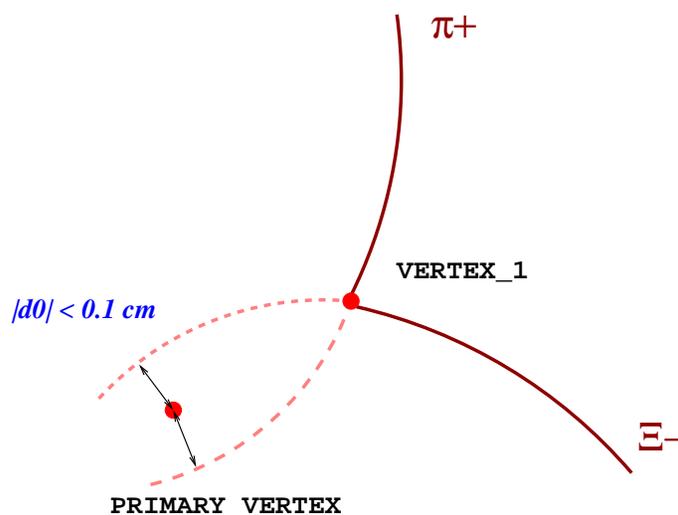
Two Track trigger data

- hyperon tracks reconstructed in SVX are used to probe production of Ξ_b and Ω_b in decays accessible to CDF triggers (**work in progress**)

Charmed-Strange baryons

$$\Xi_{3/2}^{0,--} \rightarrow \Xi^- + \pi^{+,-}$$

$$\hookrightarrow \Lambda \pi^-$$



CDF $\Xi^- \pi^\pm$ spectra

$$\Xi(1860)^{--,0} \rightarrow \Xi^- + \pi^{-,+}$$

$$\hookrightarrow \Lambda \pi^-$$

fit function:

$$\begin{aligned} \mathcal{F} &= BW \otimes Gauss + \\ &= \left(\sum_{n=0}^3 a_n \cdot x^n \right) \cdot \sqrt{x - M_\Xi - M_\pi} \end{aligned}$$

Γ is fixed to PDG value of 9.1 MeV/c²

$$N(\Xi(1530)) = 2,182 \pm 92$$

$$M = 1,5320 \pm 0.5 \text{ MeV}/c^2$$

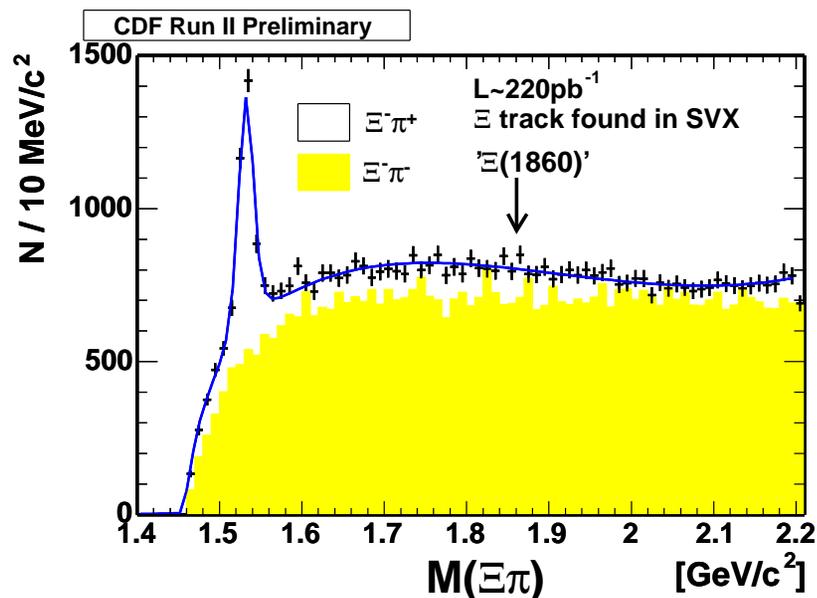
$$\frac{\sigma(pp \rightarrow \Xi(1530)) \cdot a(\Xi(1530))}{\sigma(pp \rightarrow \Xi) \cdot a(\Xi)} \sim 0.061$$

(similar to NA49)

→ displaced trigger sample, SVX tracked

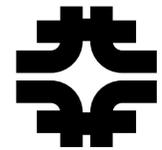
Ξ^-

→ require prompt Ξ^- , $|d_0(\Xi^-)| < 0.015 \text{ cm}$



Channel	# of events	UL	90 % CL	UL	95 % CL
$\Xi^- \pi^+$	57 ± 51	126		144	
$\Xi^- \pi^-$	-54 ± 47	51		63	

displaced trigger sample is biased towards $c\bar{c}, b\bar{b}$
 check on unbiased soft $E_T > 20 \text{ GeV}$ jet data



CDF $\Xi\pi^\pm$ spectra

- $E_T > 20$ GeV jet trigger data, SVX tracked Ξ^\pm
- require prompt Ξ , $|d_0(\Xi)| < 0.015$ cm

$$N(\Xi(1530)) = 387 \pm 34$$

$$M(\Xi(1530)) = 1,532.3 \pm 0.8 \text{ MeV}/c^2$$

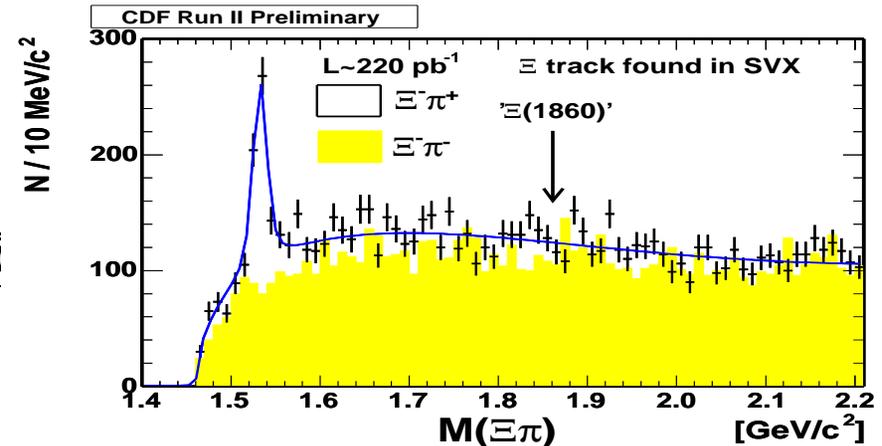
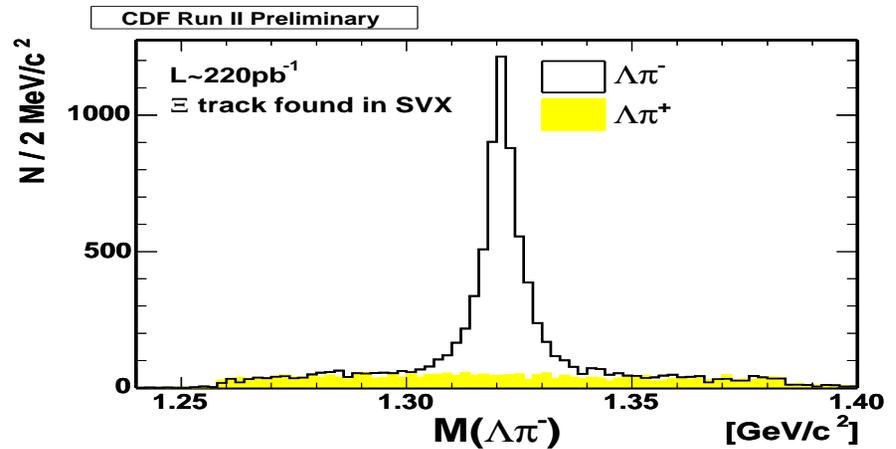
$$\sigma = 5.8 \text{ MeV}/c^2 (\text{fixed})$$

$$\frac{\sigma(pp \rightarrow \Xi(1530)) \cdot a(\Xi(1530))}{\sigma(pp \rightarrow \Xi) \cdot a(\Xi)} \sim 0.08$$

(similar to TTT sample and similar to NA49)

Channel	# of events	UL	90 % CL	UL	95 % CL
$\Xi^- \pi^+$	-14 ± 19	25		30	
$\Xi^- \pi^-$	-4 ± 18	28		33	

- $N(\Xi) = 4,870 \pm 122$. Statistics is twice compared to NA49





Summary numbers

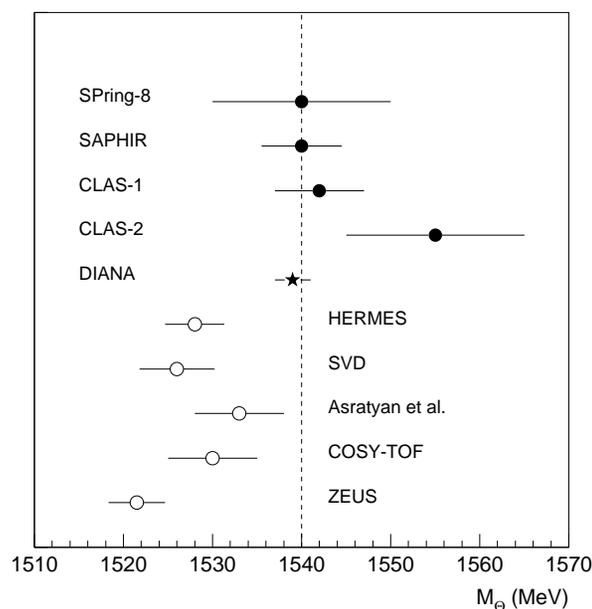
Relative yields of $\Xi(1860)/\Xi(1530)$ assuming equal detector efficiency
TTT data

yield	UL 90 % CL	UL 95 % CL
r_{CDF}^0	0.06	0.07
$r_{\text{CDF}}^{\bar{\bar{}}}$	0.03	0.04

JET20 data

yield	UL 90 % CL	UL 95 % CL
r_{CDF}^0	0.06	0.08
$r_{\text{CDF}}^{\bar{\bar{}}}$	0.07	0.09

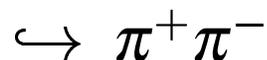
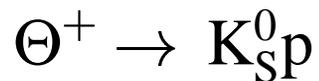
Θ^+ Mass Status



Experimental data on narrow baryon decaying to pK_S^0 (open circles) and to $K^+ n$ (solid circles), DIANA collaboration observes both modes



CDF Θ^+ search



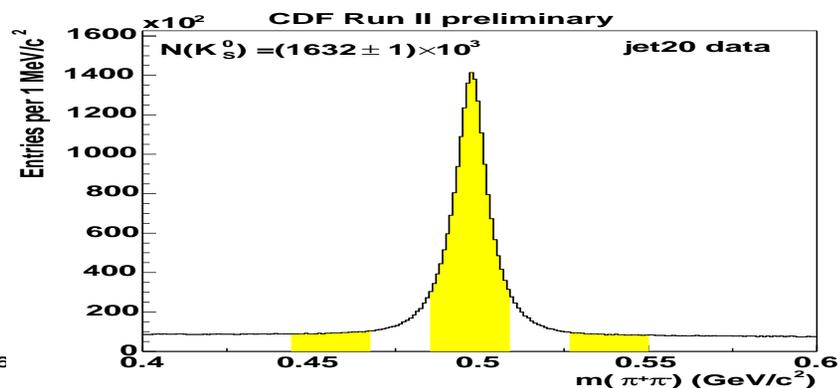
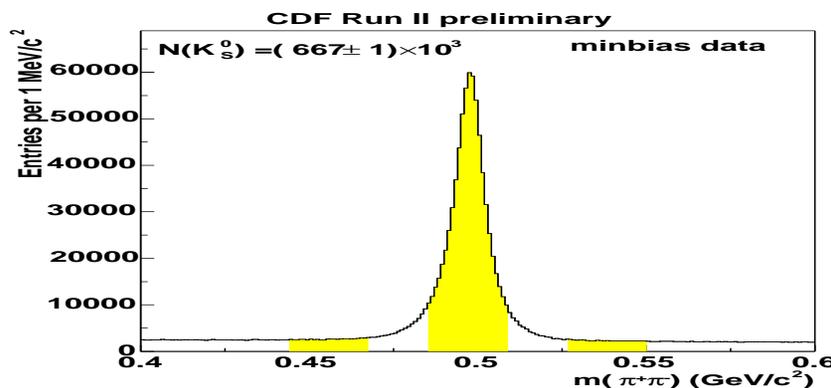
→ use TOF to identify protons $0.5 < p_T < 2.1 \text{ GeV}/c$

→ Data samples used:

● MINBIAS, 12×10^6 events, ZEROBIAS, 8×10^6 events

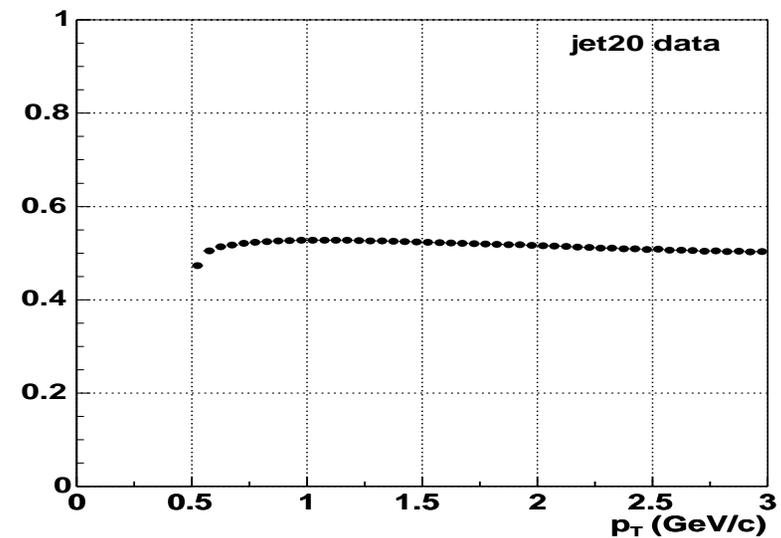
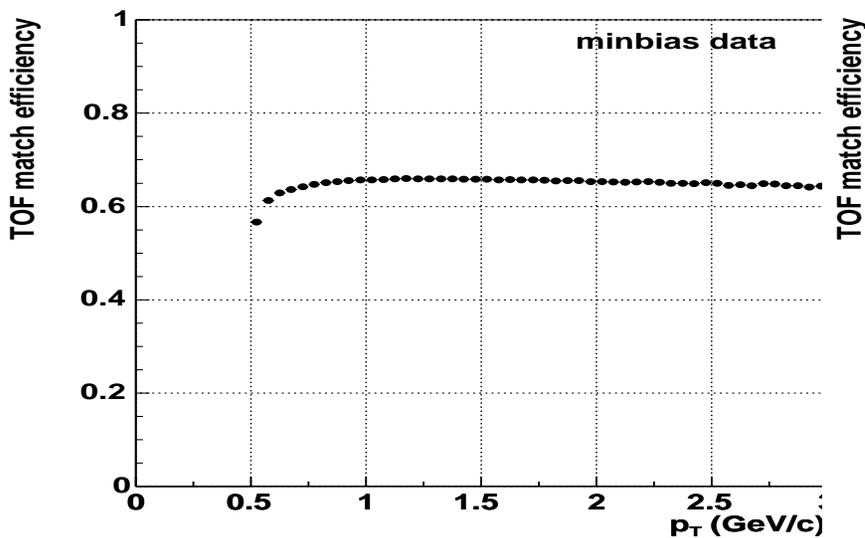
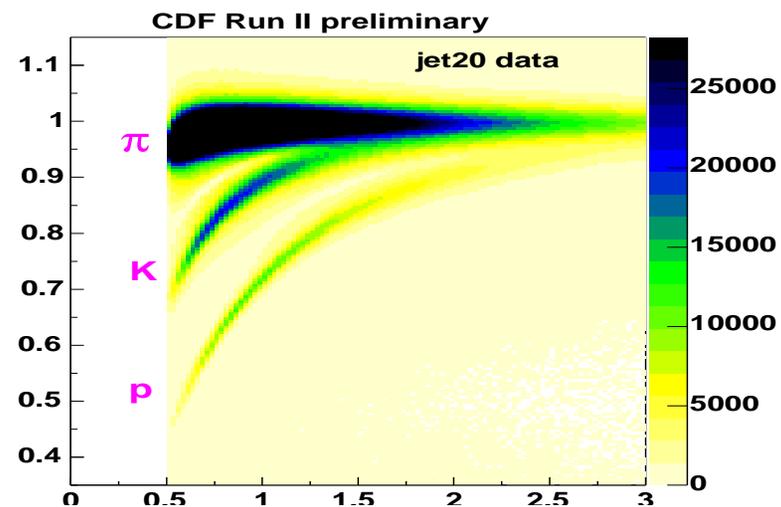
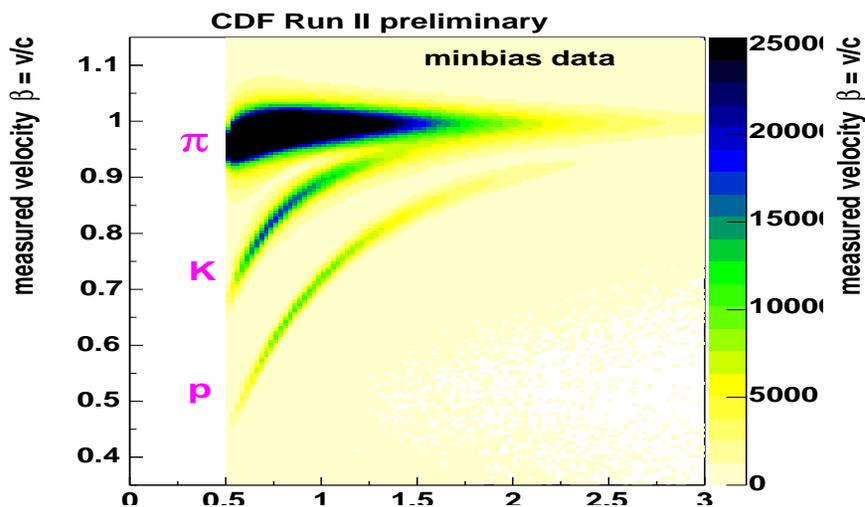
● JET20 16×10^6 events (Jet with $E_T > 20 \text{ GeV}$)

→ Feb 2002 – August 2003 data, $\mathcal{L} \approx 180 \text{ pb}^{-1}$



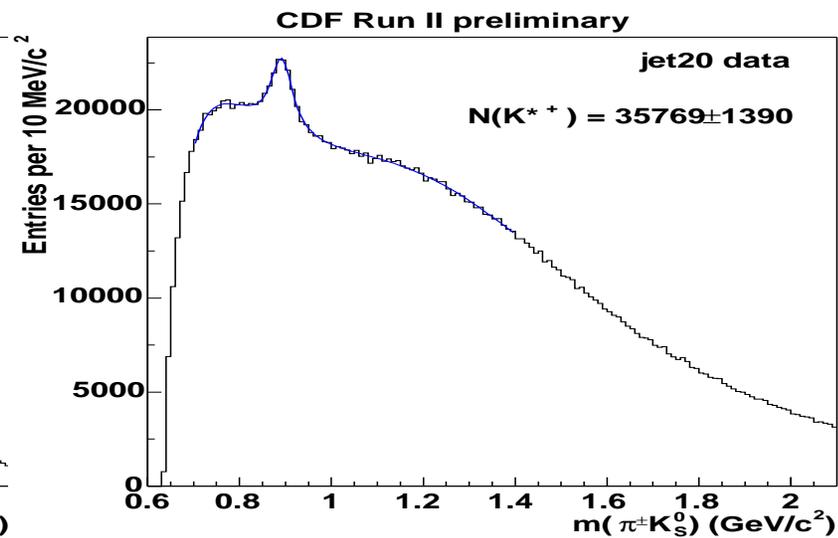
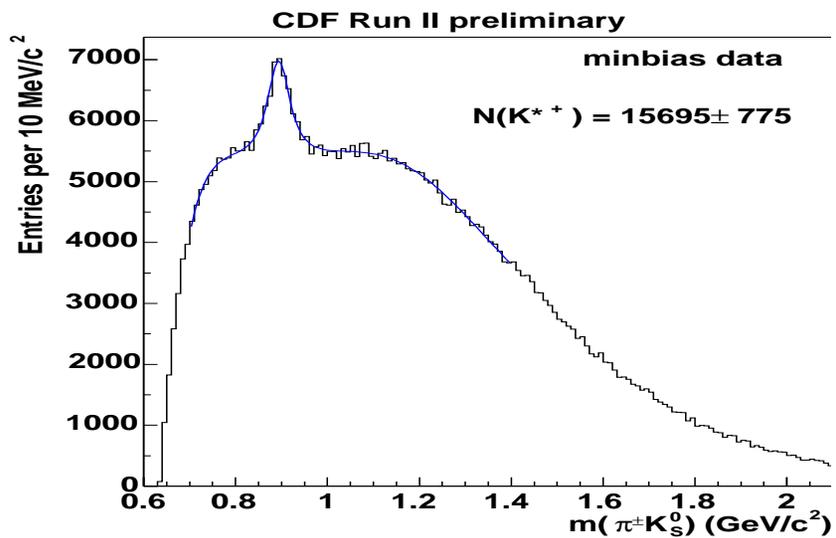
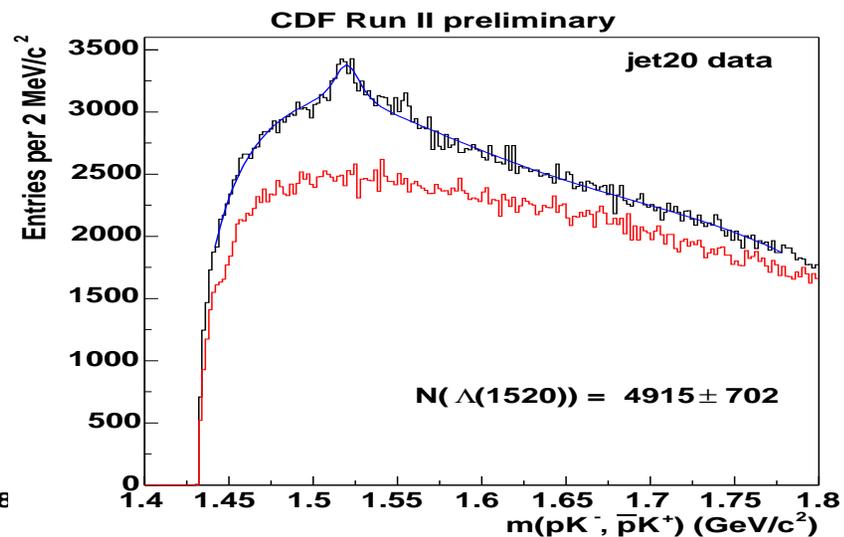
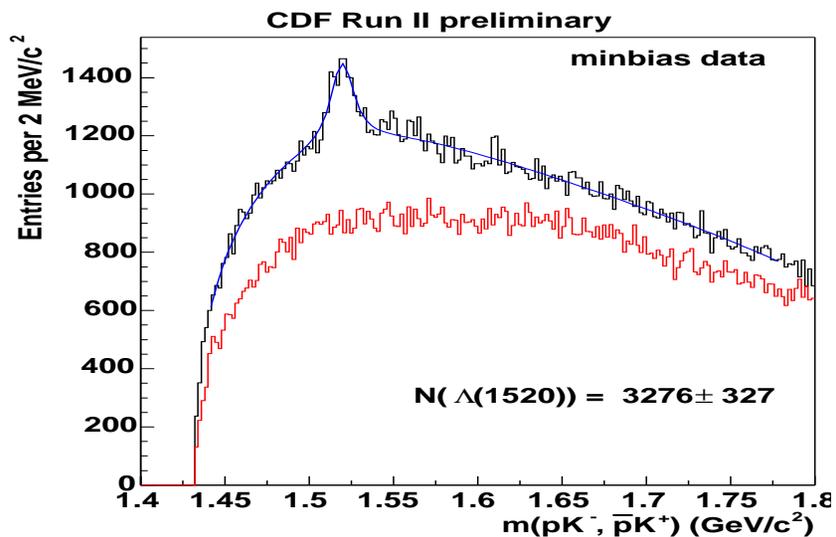


ToF performance



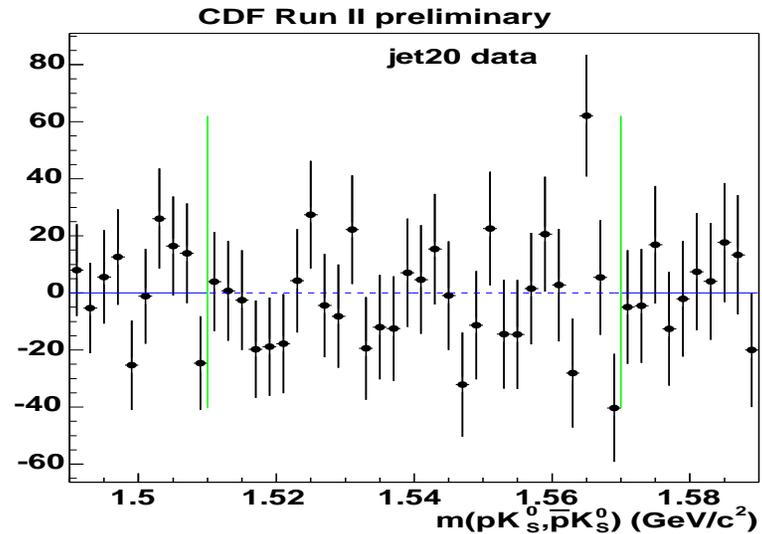
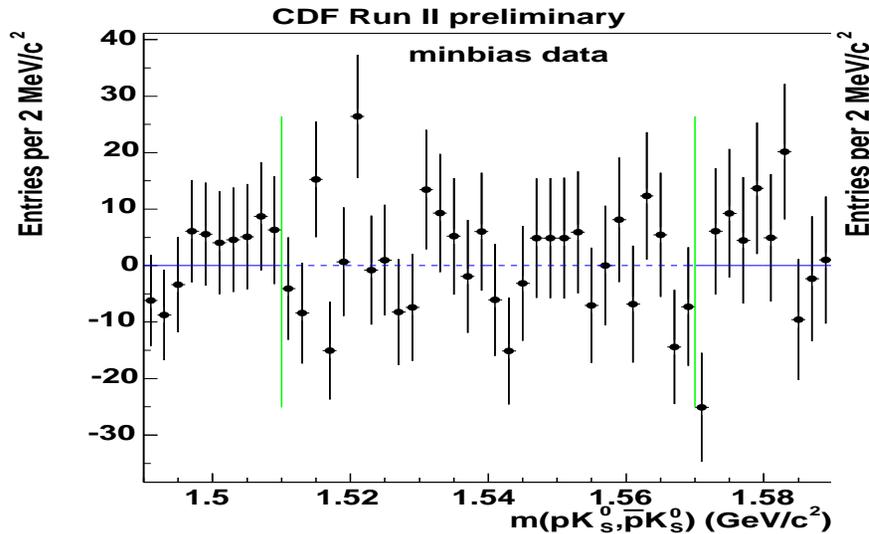
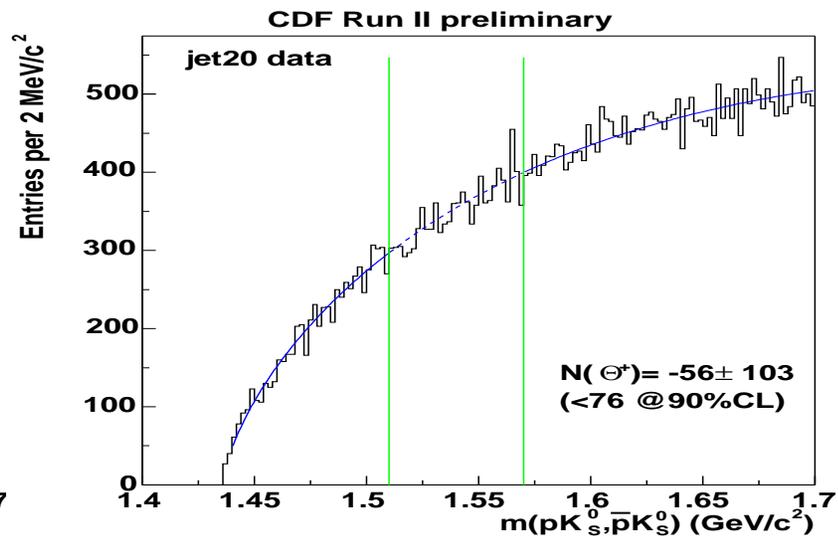
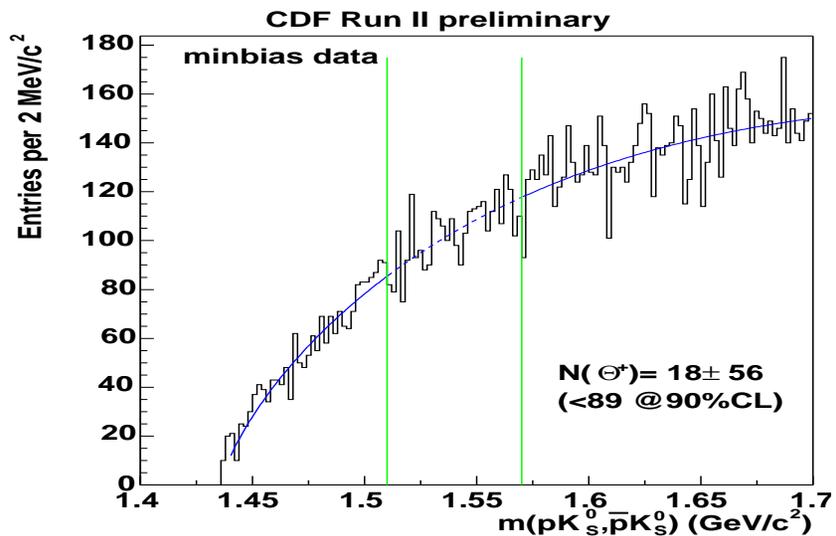


Known Resonances





The Signal



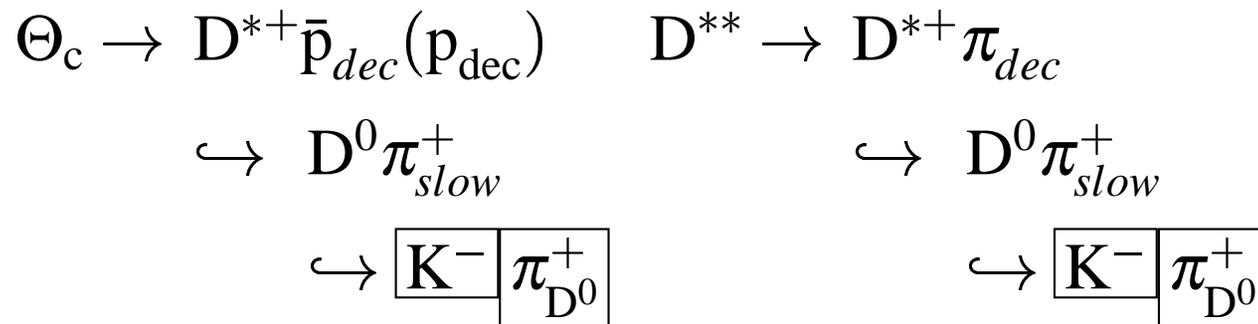
No Signal :(



Yields

Resonance	Minbias data	Jet20 data
$\phi \rightarrow K^+ K^-$	$19,721 \pm 273$	$26,658 \pm 385$
$\Lambda \rightarrow p K^-$	$3,276 \pm 327$	$4,915 \pm 702$
$K^{*+} \rightarrow K_S^0 \pi^+$	$15,695 \pm 775$	$37,769 \pm 1,390$
$\Theta^+ \rightarrow p K_S^0$	18 ± 56	-56 ± 103
90% CL limit on Θ^+	< 89	< 76

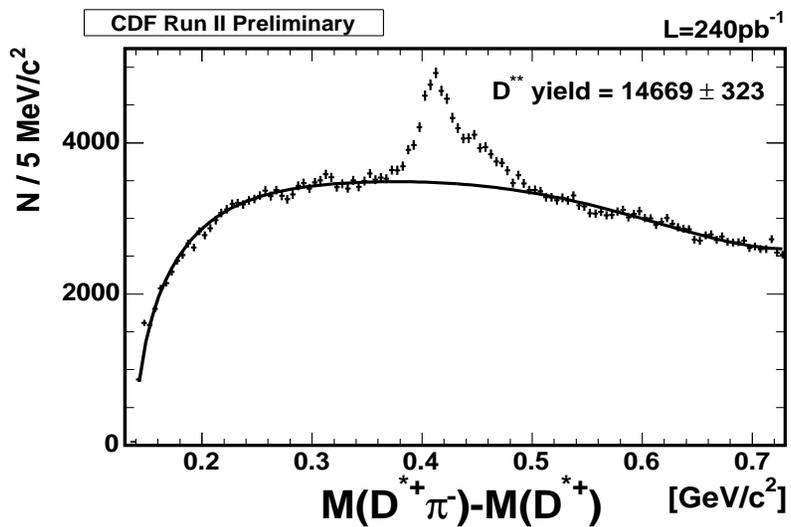
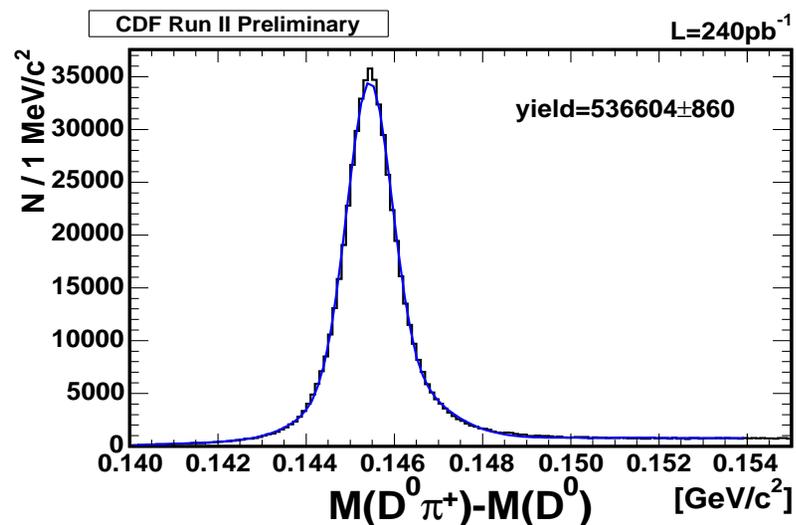
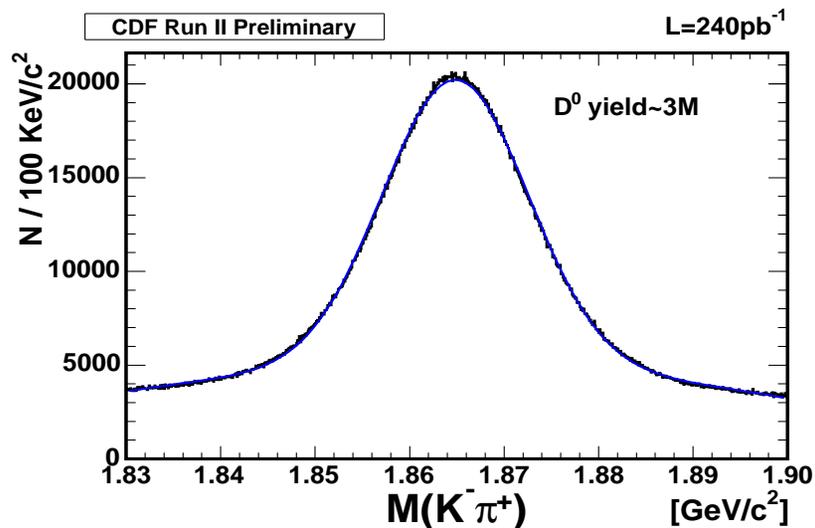
👉 presented at APS'04

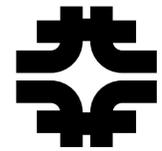


-  Use both TOF and dE/dx to identify proton in appropriate momentum ranges
-  displaced trigger data, $\mathcal{L} \approx 240\text{pb}^{-1}$
-  D^{**} as reference channel
-  $D^0 \rightarrow K^- \pi^+$ pass SVT-track trigger track match. Trigger cuts confirmed on off-line tracks.



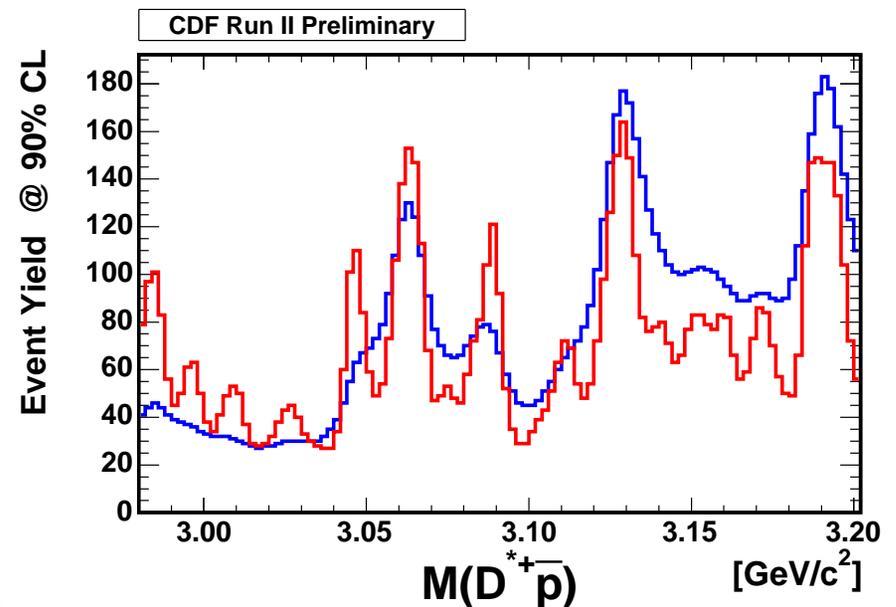
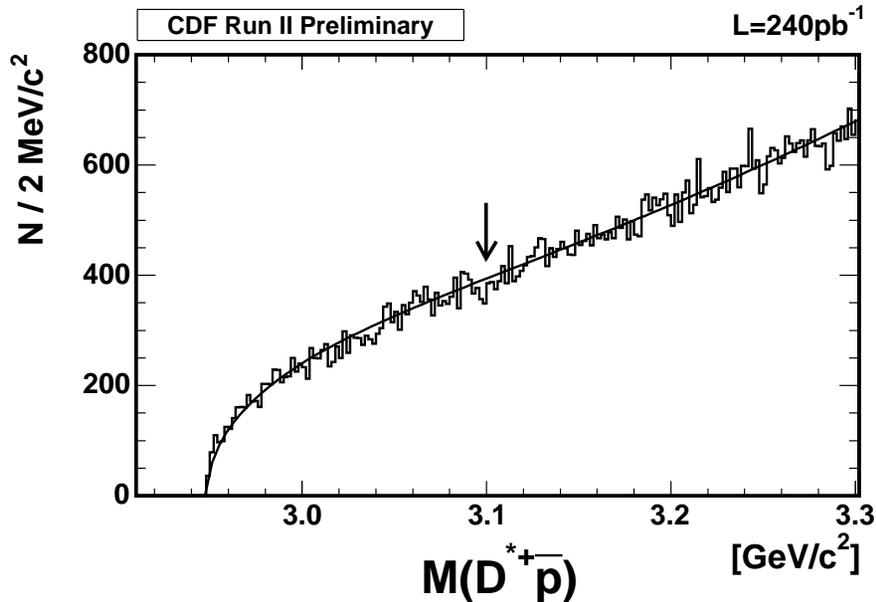
$D^0/D^*/D^{**}$ Signals





Θ_c^0 Signal no PID

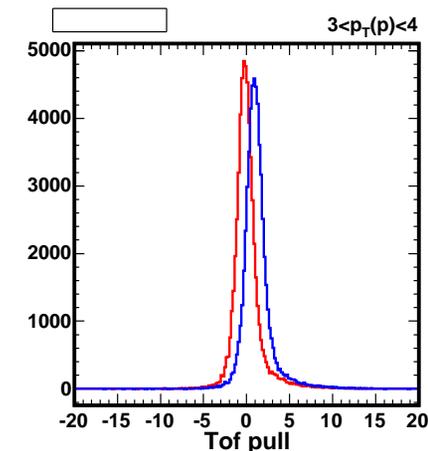
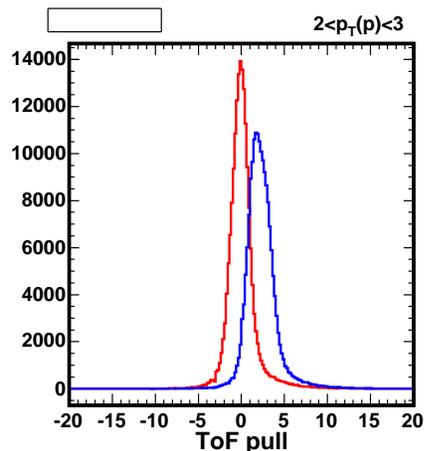
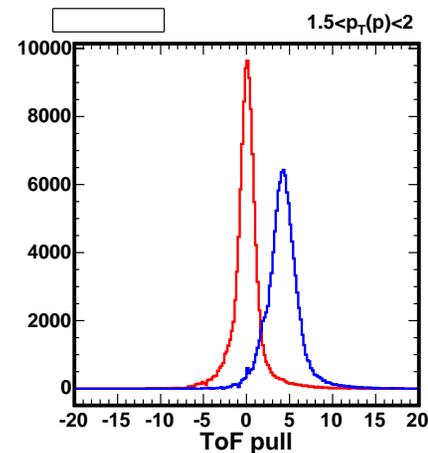
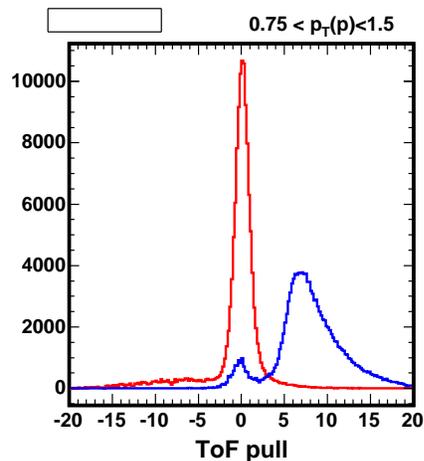
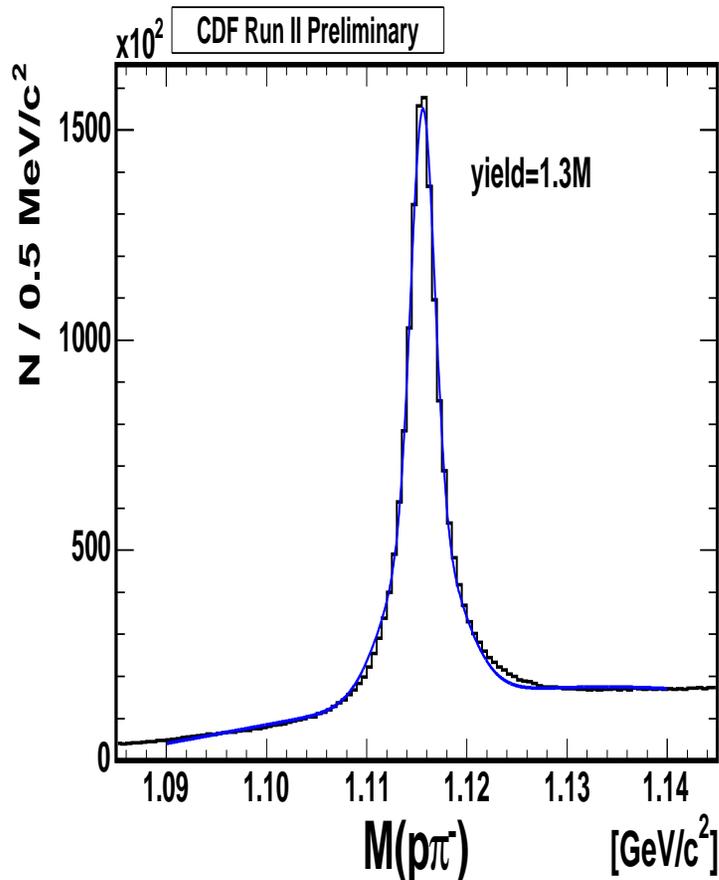
$$M(D^{*+}\bar{p}) = M(D^{*+}\bar{p}) - M(D^{*+}) + 2.010 \text{ GeV}/c^2$$



- $\Gamma = 0 \text{ MeV}/c^2$: 29 (90% CL) and 37 (95% CL)
- $\Gamma = 12 \text{ MeV}/c^2$: 44 (90% CL) and 57 (95% CL)

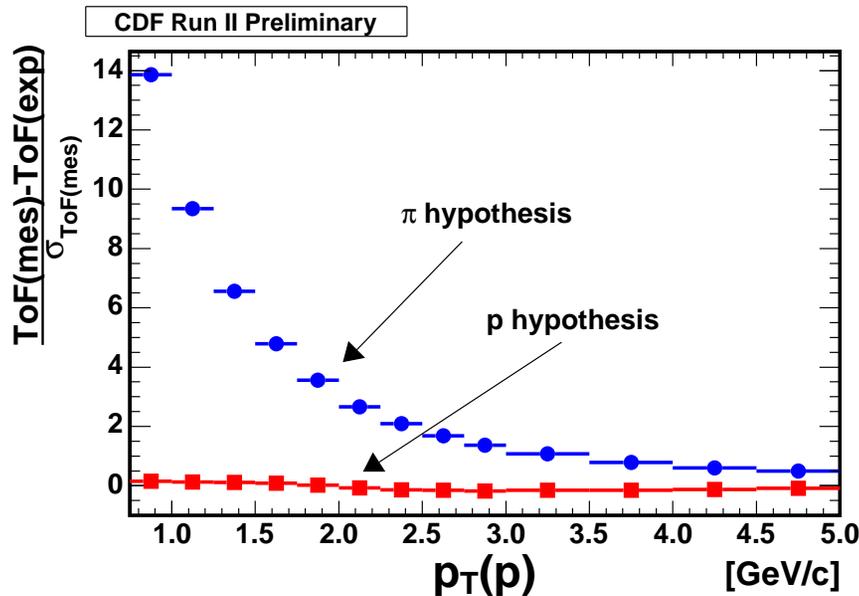
Upper limits on the number of events vs mass , red – $\Gamma = 0 \text{ MeV}/c^2$, blue – $\Gamma = 12 \text{ MeV}/c^2$

ToF

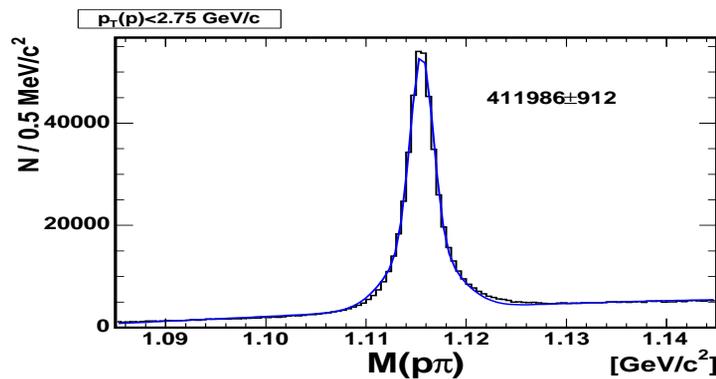


ToF pulls $((\text{ToF}(\text{mes}) - \text{ToF}(\text{exp})) / \sigma_{\text{ToF}})$ for protons from Λ for proton (red) and pion(blue) hypotheses in diff proton p_T

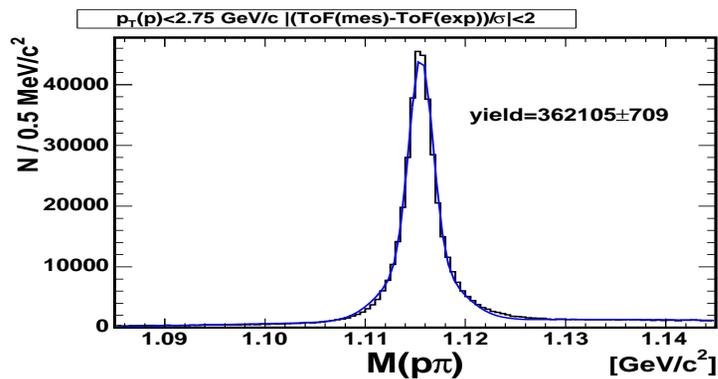
ToF Separation



● $p_T(p) < 2.75 \text{ GeV}/c$, $|(\text{ToF(mes)} - \text{ToF(exp)})/\sigma_{\text{ToF}}| < 2$



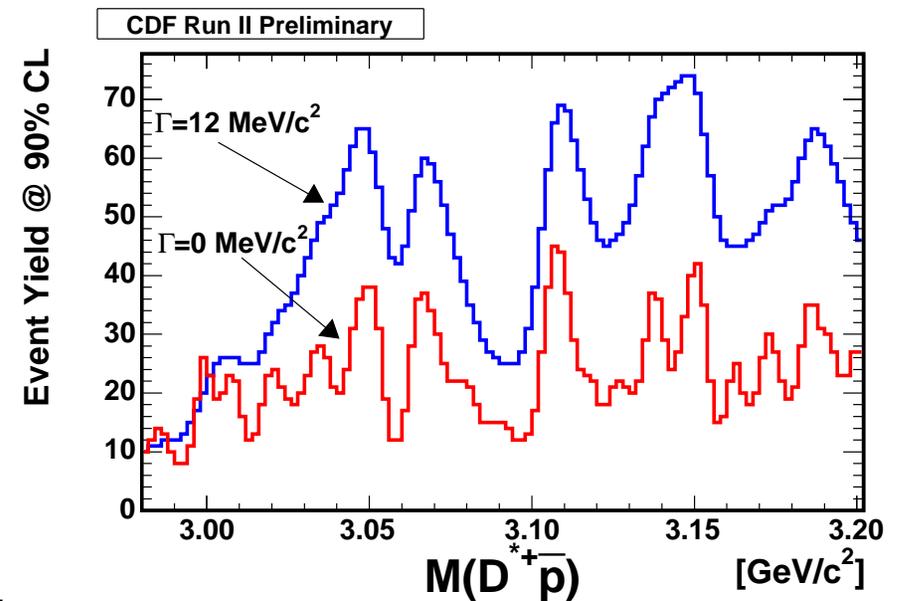
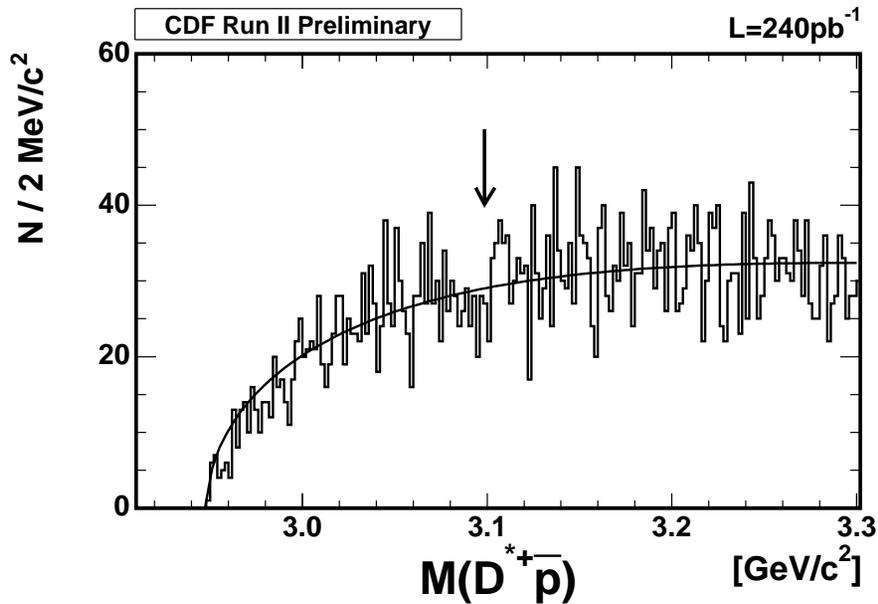
without cut



with cut

with ToF

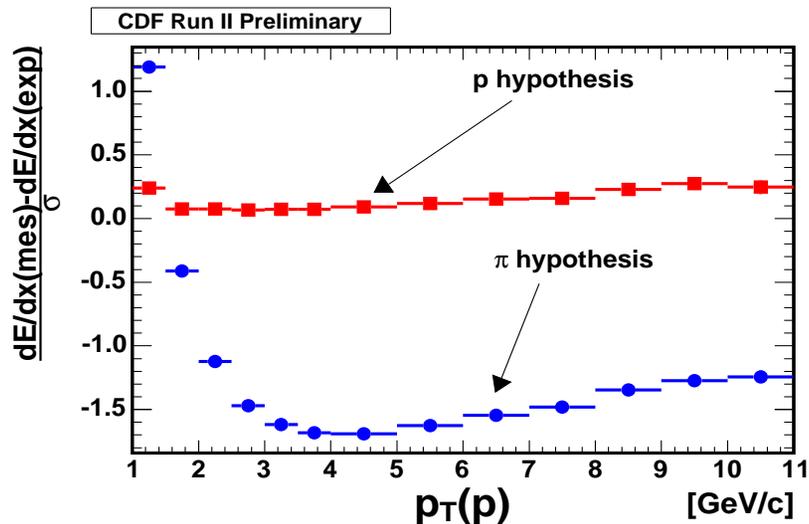
$\left| \frac{(\text{ToF}(\text{mes}) - \text{ToF}(\text{exp}))}{\sigma_{\text{ToF}}} \right| < 2, p_T(p) < 2.75 \text{ GeV}/c$



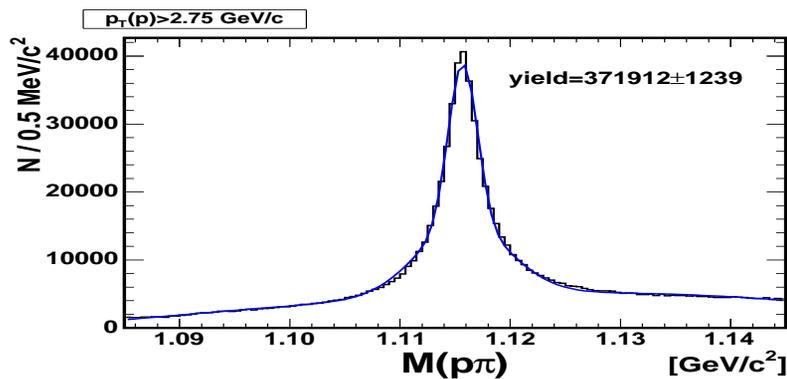
- $\Gamma = 0 \text{ MeV}/c^2$: 12 (90% CL) and 15 (95% CL)
- $\Gamma = 12 \text{ MeV}/c^2$: 25 (90% CL) and 32 (95% CL)

Upper limits on the number of events vs mass

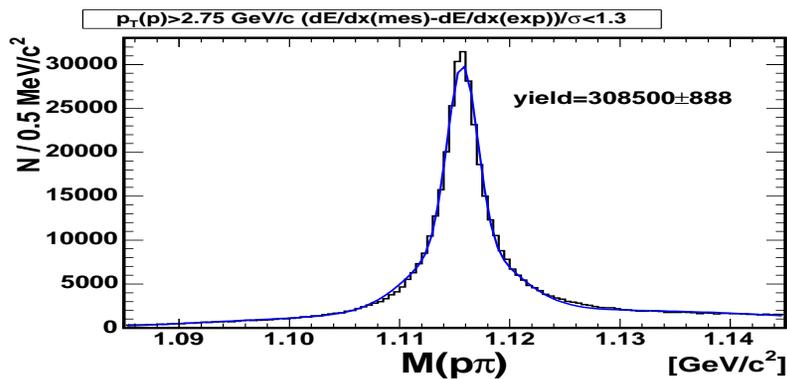
dE/dx Separation



➡ $\left| \frac{dE/dx(\text{mes}) - dE/dx(\text{exp})}{\sigma_{dE/dx}} \right| < 1.3, p_T(p) > 2.75 \text{ GeV}/c$



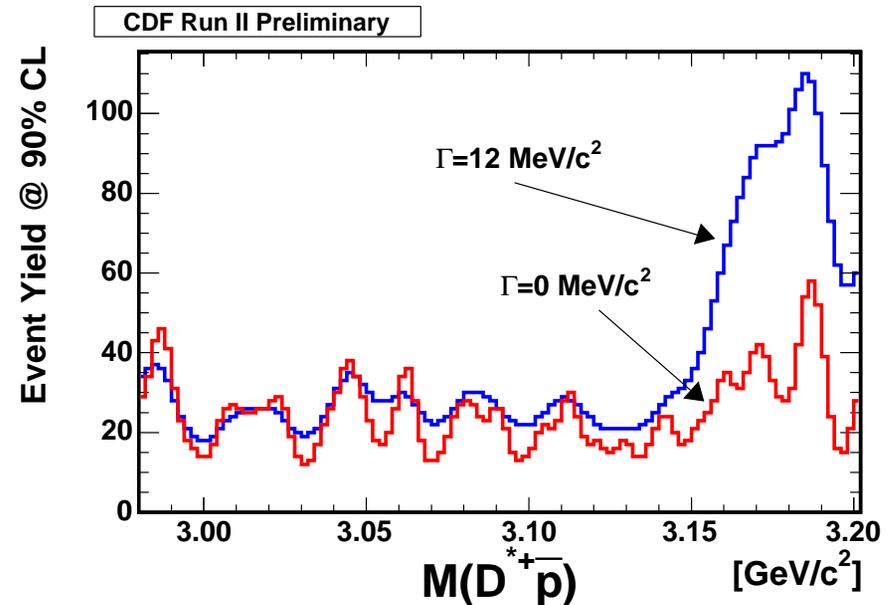
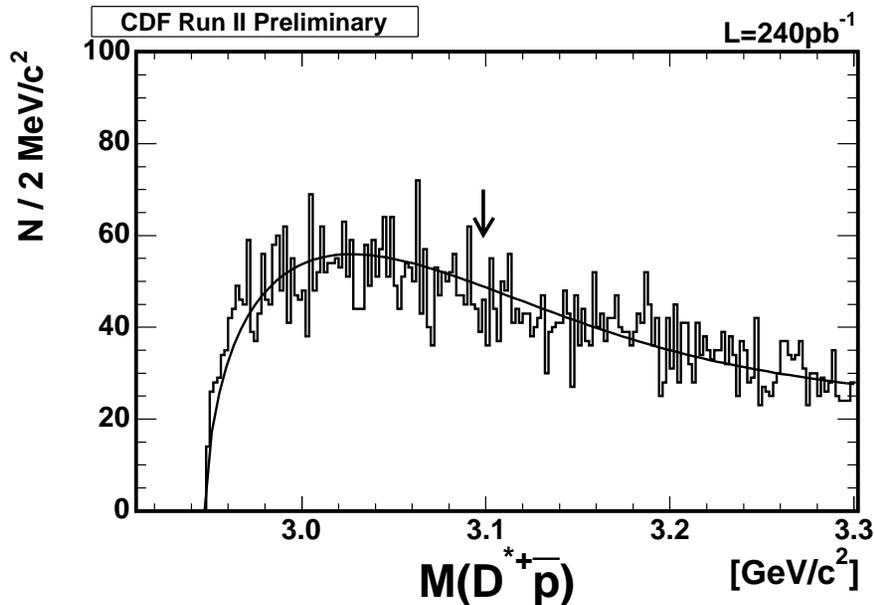
without cut



with cut

with dE/dx

$\left| \frac{dE/dx(\text{mes}) - dE/dx(\text{exp})}{\sigma_{dE/dx}} \right| < 1.3, p_T(p) > 2.75 \text{ GeV}/c$



- $\Gamma = 0 \text{ MeV}/c^2$: 19 (90% CL) and 24 (95% CL)
- $\Gamma = 12 \text{ MeV}/c^2$: 30 (90% CL) and 38 (95% CL)

Upper limits on the number of events vs mass



Conclusion/Outlook

- ➔ CDF performed search for exotic baryon states $\Xi(1860)$, Θ^+ , Θ_c . No signals found, limits on relative yields with respect to known states established.
- ➔ CDF has vigorous program of studying exotic charmed and bottom baryons exploiting its displaced track, and J/ψ triggers